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SUSTAINABILITY OF THE EUROPEAN FREIGHT TRANSPORT SYSTEM: EVALUATION OF INNOVATIVE BUNDLING NETWORKS

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Innovative freight bundling networks have emerged in the European freight transport system during the past decade and a half. This paper aims to evaluate these networks with respect to a given set of evaluating attributes (criteria). The objective is to identify the network with 'promising' or 'preferable' configuration and performance, which will be competitive to road haulage under given circumstances.

A set of different cases of rail-based innovative bundling networks represents the evaluation alternatives. The main indicators of the network demand, supply, time and cost performances have been used as the attributes (evaluation criteria). The Simple Additive Weighting (SAW) multi-criteria method has been applied to select the 'promising' or 'preferable' bundling network under given circumstances. The outcomes indicate that, generally, a 'preferable' configuration of the rail-based bundling networks should consist of a great number of nodes (inter-modal terminals) and routes covering a wide spectrum of delivery distances. In addition, both a high frequency of regular services and standardised delivery time of loading units should be provided.

Keywords: Freight transport; Inter-modality; Freight bundling;
Networks; Multi-criteria evaluation; Rail

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1 INTRODUCTION

Innovative bundling networks have been launched to contribute to the future sustainable development of the European freight transport system. Particularly, they have been expected to strengthen the market position of the inter-modal freight transport system, provide efficient taking over of freight from congested roads, and more efficient utilisation of both transport and loading systems represented by the railways and inland waterways, and containers, swap bodies and semi-trailers, respectively. Consequently, they have expected to be able to increase overall efficiency of the transport system, to significantly replace road haulage on a wide spectrum of freight delivery distance(s) (transport market(s)), and thus significantly reduce its negative impacts on the environment.

Innovative bundling networks have been based on new (innovative) organisation of transport and transshipment services and deployment of new transshipment technologies at inter-modal terminals, where the exchange of loading units between the same and/or different transport modes takes place (EC, 1997a,b). Carrying out the shuttle services and appropriate balancing of the inbound and outbound transport services at the inter-modal terminals represent the innovations in the *organisation* of transport services. In addition, the transport (network) operators have applied advanced mobile units (trucks, special rail cars, and barges) to transport the containers, swap-bodies, and semi-trailers between their origins and destinations. New *transshipment technologies* have been primarily intended to increase the terminals' throughput (capacity) and speed-up the transshipment operations (i.e., to reduce the terminal time). They have requested the introduction of new organisation of transshipment and storage services and new terminal layouts.

The TERMINET project has dealt with the identification, analysis, classification and evaluation of innovative bundling networks (EC, 1997a,b; 1998a,b). Apart from bundling networks, the project has dealt with NG (New Generation) inter-modal terminals. The innovative concepts of bundling networks operated in Europe have been identified and analysed by using surveys and interviews of actors, i.e. the network (transport) and terminal operators. In addition, the particular real-life cases of bundling networks have been classified according to two criteria-dominant transport mode and basic bundling model (configuration).

Evaluation has been carried out with the aim to identify a 'promising' or 'preferable' bundling configuration. For that purpose, a set of evaluation criteria (the attributes) on network performance has been defined and quantified for selected real-life cases. The multiple-criteria evaluation procedure has been examined for obtaining 'promising' layout(s) of particular classes of bundling networks.

This paper presents a part of the research carried out in the project TERMINET. In particular, it deals with the multi-criteria evaluation of the rail-based concepts of innovative bundling networks. The objective is to provide the methodological background for identifying a 'preferable' or 'promising' network configuration given selected network performance. The paper consists of five sections. Section 2 describes the most important operating characteristics of different types of innovative bundling networks as well as a classification of network types to be evaluated. Section 3 deals with the main indicators (the attributes) of performance of innovative bundling networks. Section 4 describes the Simple Additive Weighting (SAW) multi-criteria evaluation method to be used in the evaluation. Its application is presented in Section 5 where the selection process of 'preferable' or 'promising' bundling networks among several alternatives is presented. The last section (6) presents conclusions.

2 TYPES OF INNOVATIVE BUNDLING NETWORKS

Classification of innovative bundling networks carried out in the TERMINET project with respect to dominant transport mode has uncovered the existence of the rail-based, RO-RO, barge-based (i.e., inland navigation) and node-based bundling networks. Classification of the same sample of bundling networks with respect to a basic bundling model has identified five types of bundling network. These are: the 'point-to-point' network ($P-P$), the network of 'trunk line with collecting/distribution forks' (TCD), the 'hub-and-spoke' network (H or HS), the 'line' or 'ring' network (L), and 'mixed' (M) networks (EC, 1997a; 1998a). A common characteristic of all these networks has been to bundle the freight flows having originally a diffuse spatial pattern to become suitable for transportation by regular and a relatively frequent rail and/or barge transport.

- The '*point-to-point*' networks have been established to serve large and regular freight flows between particular origins and destinations. The loading units are collected by pre-road haulage and concentrated at the origin (begin-)terminal. After being transhipped from truck to direct or shuttle train(s) (or barge(s)), they are transported to the destination (end-)terminal. There, they are unloaded and distributed to the final customers by end-road-haulage.
- As the observation of bundling processes has been expanded to the total inter-modal chain, most of the '*point-to-point*' networks have been actually recognised as networks of '*trunk line with collecting/distribution forks*'. The trunk and feeder services are provided in these networks. Trunk services run between any two begin- and end-terminals with necessary stops at CD-terminals (EC, 1997a,b). At CD-terminals, the trunk trains/barges have been loaded by loading units, which have arrived by feeder services from the other begin-terminals. After arrival at the CD-terminal at the end of trunk line, trunk trains (or barges) stop to be partly unloaded. After that, they proceed to one of the end-terminals. The loading units, which have been unloaded at a CD-terminal, are distributed by feeder services (train or barge) to the end-terminals. Thus, feeder services are run exclusively between begin- and end-terminals, and their corresponding CD-terminals. Trunk services may move through the whole network. In some cases, additional bundling can be realised at the intermediate terminals located along the trunk line (EC, 1997a; 1998a).
- The '*hub-and-spoke*', *H* or *HS* bundling network has emerged particularly in rail and barge freight operations. In the horizontal plane, this network looks star-shaped. The network consists of several begin-/end-terminals (the spokes) and one centrally located (intermediate-)terminal (hub). At the spokes, the loading units enter and/or leave the network. At the hub, they are exchanged between transit units (trains and/or barges). The time of their staying in the terminal may vary from several minutes to several hours dependent on the inbound and outbound timetable and applied type of exchange of loading units (EC, 1997a; 1998a).
- The '*line*' (or '*ring*') bundling networks consist of the begin- and end-terminal located at both ends of the line and several intermediate (line-) terminals located in between. The line train and/or barge

services have been scheduled between the begin- and end-terminal. They may stop at one and/or few intermediate terminals where the exchanging of loading units between the same and/or different transport modes can take place. The pre- and end-road haulage is also provided at this type of bundling network (EC, 1997a; 1998a).

- Networks of 'mixed' type have been identified as a specific sub-class of innovative bundling networks. Usually, these networks consist of elements of four basic bundling networks. At these networks, independent of their location and function, the terminals usually operate to consolidate simultaneously the flows to different markets.

The simplified schemes of four basic types of bundling models are presented in Figs. 1–4, respectively.

In this paper, the evaluation of innovative bundling networks is based on 15 cases of rail-based bundling networks. There have been three cases of *P-P* bundling networks, the 'Jamsankoski Paper Mill' that consists of the rail sub-net and sea sub-net, the 'RailRoads' and the 'RoadRailer'. Six cases of bundling networks of type *H* or *HS* have been identified. These are the 'Wembley EFOC', which consists of domestic and international sub-net, the 'Hub of Metz and Quality Net' that consists of ten domestic and international quality sub-nets, and

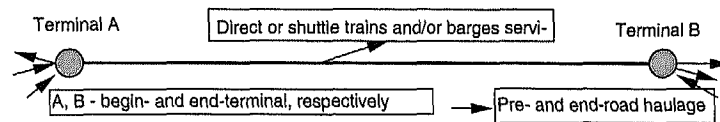


FIGURE 1 The 'point-to-point' bundling network (*P-P*).

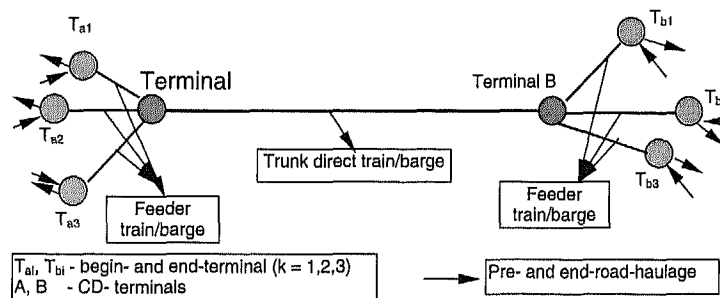


FIGURE 2 The network of 'trunk line with collecting/distribution forks' (TCD).

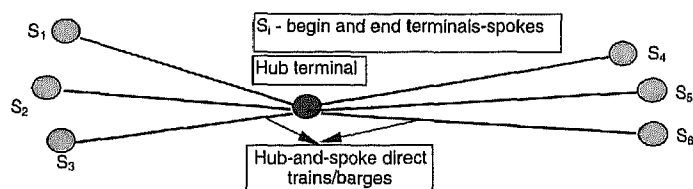
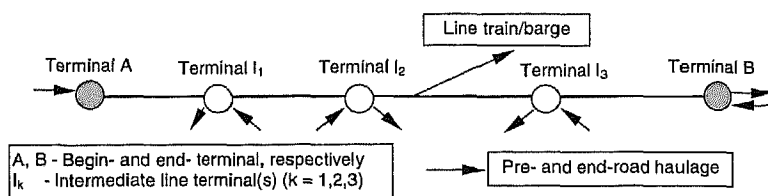
FIGURE 3 The 'hub-and-spoke' bundling network (*H* or *HS*).

FIGURE 4 The 'line' bundling network.

'Drehscheiben' concept (which has not been analysed due to lack of relevant data), the 'NEN – North European Network', which contains seven domestic and international sub-nets, and the 'Bahntrans' concept composed of the road and rail sub-net. Conditionally, the 'Gateway Terminal Hupac', which consists of a domestic and international sub-net, has been classified in this class of bundling networks. Three cases have been identified as the bundling networks of type *L*. These are the 'Piggy-Back Consortium' (which has not been analysed due to lack of relevant data), the 'Ring-Zug Rhein-Rhur' network, and 'The Linienzug' network, which consists of the sub-nets of direct and feeder services. As well, three cases have been identified as the networks of type *M*. These are the 'Voltri network' which consists of a sea and inland sub-net, the 'Sogemar network', which consists of domestic and international sub-net, and 'FlexNode' network (which has not been analysed due to lack of relevant data) (EC, 1997a; 1998a).

3 INDICATORS OF NETWORK PERFORMANCES

Generally, the performance of an innovative bundling network is a composite measure of its quantitative and qualitative spatial, technological

and operating characteristics. Performance of a bundling network can be presented by quantitative and qualitative 'indicators', 'attributes' or 'measures' (EC, 1997a; Hay, 1977; Manheim, 1979; Tarski, 1987; Vuchic, 1981). This section addresses the most important *quantitative indicators* on the performance of innovative bundling network(s). At the end of this section, some *qualitative indicators* are also explained (EC, 1997a). These indicators can be applied by different groups of actors interested in the evaluation of innovative bundling networks. These may be the users (shippers), the network (transport) and terminal operators, the producers of transport and terminal infrastructure, facilities and equipment, as well as public authorities, consultants, transport and economic planners and other decision makers. In the evaluation procedure they all may weigh differently the particular indicators of network performance and apply them as criteria to identify the 'preferable' network. In this paper, the quantitative indicators of performance of bundling networks are defined. In addition, their importance for particular interest group is explained. They are the following (EC, 1998a; Tarski, 1987; Vuchic, 1981):

(1) *Size (S)* is one of the most important characteristics of a bundling network. Physical features like the number of inter-modal terminals (nodes), routes (the links), as well as the number of uni-modal and/or multi-modal sub-networks can be applied to quantify this indicator. In particular, number of terminals reflects accessibility of network services; with their geographical (spatial) distribution, they define the network's area coverage. Number of routes expresses the spatial extension of network services. The number of uni-modal and/or multi-modal sub-networks reflects network complexity. This indicator is always preferred to be as great as possible to provide higher physical (spatial) accessibility of network services to potential users and thus its stronger 'spatial' competitiveness.

(2) *Average route length (ARL)* expresses the average travel distance of transport units (the vehicles) while in the network. It is an important indicator of the spatial performance of bundling networks, which can be determined either for the bundling network as a whole, its sub-networks and/or particular routes operated by the same and/or different transport modes. The significance of this indicator is dependent on its maximum and minimum value, which indicates how the spatial coverage of the network can compete with road haulage on a chosen spectrum

of distances. On the one side, this indicator is preferred to be as low as possible. On the other, it is preferred to be as long as possible. That is, 'preferable network' should be able to offer simultaneously services from extremely short (previously exclusively 'reserved' for road-haulage) to 'extremely' long freight delivery distances where rail, inland waterway and barge modes are dominating.

(3) *Capacity of transport unit (CT)* is another important indicator of network performance. The total volume (or weight) of freight that can be accommodated on a single transport unit (vehicle) can express this indicator. It has emerged as relevant for both transport enterprises offering services in the network and users (shippers). Generally, this capacity is preferred to be as large as possible. The transport enterprises can benefit from using transport units of greater capacity since in such a way they can reduce the frequency of service in the network and thus the operating cost to serve given (expected) demand. The users may 'benefit' and 'suffer losses' at the same time. 'Benefits' are expressed by the increased possibility to place their shipments on larger transit units and thus provide them with the opportunity to leave the terminal as soon as possible (i.e., at desired time). 'Losses' are represented by longer waits for the most convenient departure due to reduced frequency.

(4) *Frequency (F)* represents the number of transport units that pass a point on a line during a given unit of time (hour, day, week). It is usually set-up to serve expected demand and provide feasible operations of transport enterprises. Under such circumstances, it is proportional to the volume of freight demand and inversely proportional to the capacity of transport unit(s) and their utilisation (load factor). From the standpoint of users, it is preferred to be as high as possible.

(5) *Schedule delay (SD)* reflects a way of interaction of demand represented by the freight shipments (containers, swap-bodies and semi-trailers) with scheduled transport services provided by bundling networks. It is defined as the time difference between desired (the most convenient) and actual departure of loading units to desired destination. Actually, it represents the waiting time of loading units at origin terminal(s). It is mostly dependent on the demand pattern, frequency (i.e., headway between successive departures) and punctuality of services (delays). Schedule delay is preferred to be as low as possible from the users' point of view. In that context, some bundling networks are more attractive (and therefore more competitive) if potential customers

will wait shorter times for departure of their shipments. In addition, this time can be of some importance for the terminal operators. Namely, dependent on the intensity of demand, length of these intervals, and the type of exchange of loading units, the accumulation (the buffers) of transit and loading units can be formed at the begin-/end-, intermediate- and hub-terminal(s). Under such circumstances, these accumulations may request additional space for short- or long-time storing. As well, in specific cases this time may determine the dwell time of the loading units in the terminal. This may happen under circumstances when the terminal time is exclusively dependent on the inbound and outbound timetable (in this case, the sequential exchange of loading units usually will take place).

(6) *Average transport speed (ATS)* is the travel speed of transport units while operating in the network. It is of particular importance for transport enterprises for many reasons. First, a higher speed shortens the transport time of transit and loading units on a given distance (route). Second, a higher speed enables operators to better utilise the existing fleet under given conditions defined by network configuration and volume of demand (generally, an increase in this speed will allow engagement of a smaller number of transit units (and loading units) under given circumstances). An increase in transport speed can increase the delivery speed of a loading unit and thus make the transport services more attractive for potential users. Anyway, from the viewpoints of both transport enterprises and users (senders), bundling networks operated at a higher transport speed will always be preferable.

(7) *Average transport time (ATT)* is the period which the transport units spend on the route connecting origin and destination terminal(s). Thus, it expresses the 'distance' separating the origins and destinations of the freight flows. Generally, it may produce two effects on transport enterprises: first, shortening the transport time of transport units can contribute to shortening the total delivery time of loading units; second, the fleet needed to serve a given volume of demand can be smaller. Similar to speed, the bundling networks which provide a shorter transport time will always be preferable.

(8) *Terminal time (TT)* represents the period that both the transport units and loading units spend in the inter-modal terminal(s) while being on route(s) between origin(s) and destination(s). This time represents a gap between two successive transport activities. Usually, it is used for

transhipment of the loading units between different transport units operated by the same or different transport modes meeting each other at the terminal(s). Terminal time influences total delivery time and thus the total delivery cycle of both the loading units and transport units. This indicator emerges as the important one for transport and terminal operators since both are interested in reducing it as much as possible. By shortening terminal dwell time, transport enterprises may offer 'faster' and more reliable services and achieve higher utilisation of their fleet. This may reduce their operating cost and increase the attractiveness of services for potential users. The terminal operators can produce two effects by diminishing terminal dwell time: first, their services may become more attractive for transport operators; second, the terminal efficiency can rise. Generally, terminal dwell time is preferred to be as short as possible in the absolute sense from the viewpoint of both the network (transport) and terminal operators. Terminals that are more efficient will indirectly require less space (land). Under such circumstances, they will be considered as more environmentally friendly facilities by relevant governmental authorities, policy makers and the public. The shortening of terminal dwell time has been much more important and desired at the bundling networks which have operated shorter rather than longer distances by higher transport speed.

(9) *Average delivery distance (ADD)* is defined as the distance between origin(s) and destination(s) of loading units measured along the transport lines. It is mostly dependent on the spatial pattern of demand. In the case of bundling networks, this indicator is preferred to be as short as possible to emphasise the competitiveness of these networks on short distances where road haulage dominates.

(10) *Average delivery speed (ADS)* is the travel speed of loading units between their origins and destinations. It is mostly dependent on transport speed and terminal dwell time. For a given delivery distance, it increases with increase in transport speed and decreases with increase in terminal dwell time. It is always preferable to be as high as possible. On a given bundling network, this can be achieved by increasing the transport (commercial) speed of transit units operated by different transport modes and shortening the terminal dwell time(s). An increase in delivery speed may have two effects on the transport enterprise. On the one side, it may accelerate the turnaround of transit and loading units and thus increase the total operating cost. On the other side, the increase in speed

will increase the number of the fleet's cycles. This will provide better utilisation and improve the overall performance of the operator's fleet. These two effects should be traded-off in order to reduce the average enterprise's unit costs.

(11) *Average delivery time (ADT)* is the travel time of loading units between their origins and destinations. It is always preferred to be as short as possible. By definition, this time will be shorter if the loading units are delivered on the shorter distances by higher delivery speed. In case of bundling networks, this will be particularly dependent on the network's spatial configuration. In addition, by shortening the terminal dwell time, delivery time will be shortened. Generally, the shortening of average delivery time can yield several macro- and micro-economic advantages. The main macro-economic advantage has consisted of time saving, which can be used either for additional production (thus the processes of production and turnover can be accelerated) or for other (non-transport) productive activities. Both transport enterprises (operators) and users can obtain the main micro-economic advantages. The transport enterprises can reduce the size of fleet required and thus the total costs to serve a given volume of demand. In addition, they can increase the number of cycles (frequency) of the existing fleet in the network of fixed configuration. This will increase the total cost and reduce the unit cost due to better utilisation of the existing fleet. However, in most cases the decrease in unit costs due to shortening the delivery time has been greater than the increase in total cost incurred by shortened delivery times (economies of scale). In addition, the other requirements on service quality like reliability, punctuality and regularity will be more easily met if average delivery time is shorter. The users may benefit from shortening average delivery time through improvements in service quality. Generally, higher quality of service widens the transport market, which may mean prices (freight rates) will remain relatively stable during the short-run. Consequently, it may increase the volume of demand and ultimately lead to a better utilisation of the network (the transport and terminal infrastructure, facilities and equipment).

The principal social benefit gained by shortening the average delivery time is reducing the level of 'frozen' working capital during its stay in the network. This may contribute to improvement of production and consumption processes. Thus the innovative bundling networks which

have a higher delivery speed and shorter delivery time will always be favourable.

(12) *Coefficient of terminal time (CTT)* expresses the 'share' of the terminal dwell time in the total delivery time. It is a derived indicator of network performance. It is important for the network and terminal operators and producers of terminal facilities and equipment. Normally, it is preferred to be as low as possible since terminal operations are inherently unproductive. However, they are necessary to be carried out to provide the exchange of loading units between the same and/or different transport modes. These operations take time, which should be as short as possible. As has been mentioned above, terminal dwell time is not dictated exclusively by the terminal's capabilities (capacity) but also by the network operators' inbound and outbound timetable. Hence, the terminal and network operators should make constant effort to 'improve' (reduce) the coefficient of terminal time. The terminal operators should increase the 'speed' of terminal operations either by better using the existing or introducing the new generation (NG) terminal technologies. The network (transport) operators should properly match inbound and outbound timetables on the one side, and shorten transport time on the other side.

(13) *Transport work (TW)* is the quantity of movement carried out during a given period like a day, week, month or year. It is computed as the number of transport objects (freight shipments) multiplied by the distance over which they are carried. Thus, it increases with increase in the number of freight shipments and transport (or delivery) distance. For the bundling network operators, it represents one of the simplest measures of their output. Each operator intends to achieve as great as possible output for the following reasons: greater output may reflect the operation of a larger network where larger volumes of demand are served by higher intensity of services. In competitive markets, the greater output may provide greater 'market power' and thus make the operator's position more competitive. Dependent on purpose, transport work can be measured either for particular 'interesting' routes or for the network. In the evaluation of innovative bundling networks, this indicator is preferred to be as great as possible. However, it should be considered with caution, always in combination with frequency of service and average route length. Otherwise, it may cause confusion. On the one side, it can measure the transport work carried out in the

network consisting of a small number of terminals connected by long routes where low intensity of regular service (frequency) is supplied to satisfy relatively low volumes of demand. On the other side, it can be used to measure the transport work of similar quantity carried out in the network consisting of a large number of terminals connected by extremely short routes where high intensity of regular operations (frequency) are scheduled to serve high volumes of demand. In addition, this indicator can be applied efficiently to express the potential benefits of bundling services in comparison to road-haulage with respect to effects on the environment.

(14) *Intensity of network services (INS)* is defined as the volume of transport work carried out per unit of network length per unit of time. It is preferred to be as high as possible. This indicator may be particularly relevant for local and central governmental institutions, which have permanent responsibility for balancing the development of different transport modes, provision of their proper utilisation and coordination of land-use planning.

(15) *Technical productivity (TP)* is the work carried out by one or a fleet of transport units per unit of time. It is computed as the transport unit (or fleet) capacity (or the volume of freight carried by them) multiplied by transport (operating, commercial) speed. By definition, it increases with the increase in capacity of transit units used in the network, their utilisation (load factor) and operating (commercial) speed. It is preferred to be as high as possible from the standpoint of the network (transport) operators. Larger and higher utilised transit units (vehicles) moving at higher speed are preferable given the volume of demand and network configuration (size and scope). This indicator seems to be particularly suitable for comparison of the performance of different transport modes operating in the same and/or different bundling networks.

(16) *Cost (C)* is expressed by total expenditure to operate bundling network(s). Generally, it consists of investment and operating costs of both the transport and terminal operator(s). In most cases freight rates (prices) are based primarily on cost. Therefore, the cost directly influences overall profitability and indirectly the competitiveness of the network (transport) and terminal operators (enterprises). In addition, cost may emerge as relevant for investors and/or subsidisers of the bundling network(s). (Frequently, local and central authorities can act

as sponsors of freight bundling operations. In that case, they may be interested in supporting bundling networks with lower total cost.) Consequently, it is preferred to be as low as possible.

Additional indicators of network performance such as *externalities*, *safety*, *dependability* and *reliability* can be considered as criteria for the evaluation of innovative bundling networks.

(17) *Externalities (E)* represent the costs of taxes paid by the network and terminal operators due to imposing extra costs on others. Like the other uni-modal transport operations, bundling networks may cause four types of externalities: noise, air pollution, accidents and congestion (EC, 1996). Local communities, central and international governments and their institutions are particularly interested in all environmental impacts, which are usually measured by the 'quantity' per unit of the system's output. This 'quantity' is desired to be as low as possible to guarantee a sustainable development of the transport sector. In this respect, more environmentally friendly transport modes in both absolute and relative senses will be preferred and favoured. In the case of innovative bundling networks, those which generate smaller negative impacts will be preferable. As well, those innovative bundling networks which are able to completely replace (or significantly reduce) the negative impacts of road haulage on the environment and provide higher utilisation of other more environmentally friendly modes will be favoured.

(18) *Safety (S)* addresses the risk of damage or loss of loading and transit units while in the network. The number of deaths (and injuries) per unit of output of the transport system can be used to measure the level of risk (safety). Generally, the risk of damage or loss should be as low as possible, i.e., the level of safety is preferred to be as high as possible. For evaluating innovative bundling networks, this indicator can be estimated in two ways. First, by recording past accidents which happened in the networks and terminals (or at the transport modes operating in the network). Second, these estimates can be obtained by interviewing users who may be asked to estimate the level of safety in a qualitative way. By using a convenient scale in the latter case, safety can be graded as 'low', 'satisfactory', 'good', 'excellent', etc. Later, these qualitative estimates can be converted into quantitative ones and used for evaluating the particular bundling options.

(19) *Dependability (D)* represents on-schedule delivery of shipments to end-users (the customers). This indicator can be expressed by delays

of transit and loading units (shipments), which are dependent on the 'quality' of operations of both the network and terminal enterprises. Delays are expressed by differences between the actual and scheduled (planned) time of departures and arrivals of transport and loading units at particular 'reference' locations on bundling networks. These are always the inter-modal terminals and storage facilities of the end-users. These delays are preferred to be as low as possible.

(20) *Reliability (R)* is the ratio between actually realised and planned (scheduled) services. In this context, transport services can be realised either in accordance with a timetable or on time, whichever is most suitable for the users. For example, reliability will be 'zero' if the departure fails to take place, or the transit and loading units fail to reach their destinations. Incomplete (or reduced reliability) may happen due to various factors like meteorological and climatic conditions, technical defects and failures, traffic conditions, and other reasons (strikes, etc.). Both operators and users may be interested in as high as possible values of this indicator.

With respect to their contribution to the 'feasibility of operations' of bundling networks, indicators described have been classified into 'benefit' and 'cost' indicators. By setting limits on these indicators, the 'benefit' and 'cost' evaluation criteria have been obtained, respectively. Table I presents the preferable signs of performance indicators of bundling networks as they have been applied as criteria in the evaluation. A (+) denotes a 'positive' ('beneficial') preference, i.e., as the indicator's value is higher, the corresponding network will be preferable; a (–) denotes the 'negative' ('cost') preference of the indicator, i.e., if the value of this indicator is greater the corresponding network will be less preferable.

4 THE EVALUATION METHOD

Based on the indicators in Table I, the 'preferable bundling network' can be selected in two ways. First, it can be obtained by comparing the selected authentic cases of innovative bundling networks with equivalent hypothetical cases which would be operated by road haulage (hypothetical situation). Second, comparing the bundling networks themselves can select a 'preferable bundling network'. In this paper, the

TABLE I Indicators of innovative bundling network performance and their desired preference as evaluation criteria

| Indicator | Unit ^b | Type | |
|---|-------------------|-----------|--------|
| | | 'Benefit' | 'Cost' |
| 1. Size of the network (S) | — | + | |
| 2. Average route length (ARL) | (km) | + | |
| 3. Capacity of transit unit (CT) | (TEU/TU) | + | |
| 4. Frequency (F) | (TU/h) | + | |
| 5. Schedule delay (SD) | (h) | | — |
| 6. Average transport speed (ATS) | (km/h) | + | |
| 7. Average transport time (ATT) | (h) | | — |
| 8. Terminal time (TT) | (h) | | — |
| 9. Average delivery distance (ADD) | (km) | | — |
| 10. Average delivery speed (ADS) | (km/h) | + | |
| 11. Average delivery time (ADT) | (h) | | — |
| 12. Coefficient of terminal time (CTT) | — | | — |
| 13. Technical productivity (TP) | (TEU km/h) | + | |
| 14. Transport work (TW) | (TEU km) | + | |
| 15. Intensity of network services (INS) | (TEU km/km) | + | |
| 16. Cost (C) | (ECU/TEU km) | | — |
| 17. Externalities ^a (E) | | + | |
| 18. Safety ^a (S) | | + | |
| 19. Dependability ^a (D) | | + | |
| 20. Reliability ^a (R) | | | — |

^aThese indicators are identified as relevant indicators (criteria) but not applied to 'preferable layout(s)' of innovative bundling network(s) due to lack of relevant data. ^bTEU/TU – 20' containers per transit unit; (km/h) – kilometres per hour; (h) – hours; (TU/h) – Transit Units per hour; (TEU km/h) – TEU kilometres per hour; TEU km – TEU kilometres; (TEU km/km) – TEU kilometres per kilometre of network length; (ECU/TEU km) – ECU per TEU kilometre; TEU is an equivalent for a 20' container.

latter approach is applied. According to this approach the 'preferable network' is considered to be the one which provides, in comparison to the several alternate layouts, the largest score of both 'benefit' and 'cost' performance indicators (criteria) under given circumstances, determined by existing physical, spatial and operational characteristics of bundling networks.

The evaluation method consists of three parts. These are: the basic structure of the evaluation method, the procedure for normalising the values of criteria, and assignment of weights to these criteria.

4.1 Basic Structure of the Evaluation Method

The SAW method has been applied for evaluation of the innovative bundling networks. This is one of the best-known and widely used methods of multiple-criteria decision-making (Hwang and Yoon, 1981).

In this method, the Decision-Maker (DM) assigns weights to each criteria, which represent their relative importance. Then, DM makes a numerical scaling of intra-criterion values and obtains a total score for each alternative. Multiplying the scale rating for each criterion by its importance weight and then summing these products over all criteria, we obtain the score. After the total scores have been computed for each alternative, the alternative with the highest score (the average) is the one prescribed to DM.

Mathematically, the SAW method can be presented as follows: Let m represent the number of alternatives under evaluation and n the number of criteria per alternative. Suppose that DM has assigned a set of importance weights $w = (w_1, w_2, \dots, w_n)$ to particular criteria, then the most preferred alternative, A^* , is selected such that:

$$A^* = \max_i \{A_i\} = \max_i \sum_{j=1}^n w_j r_{ij} / \sum_{j=1}^n w_j \quad \text{for } i = 1, 2, \dots, m, \quad (1)$$

where $\sum_{j=1}^n w_j = 1$, and r_{ij} is the normalised outcome of the alternative A_i with respect to j th 'benefit' criterion (cost criterion is converted to the 'benefit criterion by taking the reciprocal before normalisation).

4.2 Normalisation of the Values of Criteria

Normalisation of the criteria values represents an essential part of the application of the SAW method. It aims to obtain comparable scales. There are different ways of normalising the values of criteria such as 'vector normalisation' and 'linear scale transformation'. In the evaluation of bundling networks, the 'linear scale transformation' has been applied. It has simply been done by dividing the outcome of a certain criterion by its maximum value, provided that all criteria have been defined as 'benefit criteria' (i.e., the larger the value of the criterion, the greater its preference, and vice versa). Let x_{ij} be the outcome of criterion (j) of alternative (i). Then, the transformed outcome of x_{ij} is equal to

$$r_{ij} = \frac{x_{ij}}{\max_i x_{ij}}. \quad (2a)$$

It is clear that $0 \leq r_{ij} \leq 1$, and the outcome is more favourable as r_{ij} approaches 1. The advantage of this scale transformation is that all

outcomes are transformed in a linear (proportional) way. Thus, the relative order of magnitude of the outcome remains equal.

As both 'benefit' and 'cost' criteria exist, the 'cost' criteria can be treated as 'benefit' criteria by taking the inverse of the outcomes, and vice versa. Then, for the 'cost' criterion x_{ij} , the transformed outcome can be determined as follows:

$$r_{ij} = \frac{1/x_{ij}}{\max_i(1/x_{ij})}. \quad (2b)$$

Thus, the worst outcome of a certain criterion implies $r_{ij}=0$, and the best outcome $r_{ij}=1$ (Hwang and Yoon, 1981).

4.3 Assignment of Weights to Criteria

Different methods can be applied to assign weights to particular criteria. First, weights can be assigned by a DM according to his own expertise and experiences in the field. Second, experts can assign weights. Finally, different mathematical methods can be applied. These have proved useful in cases when it has been impossible to obtain experts' weights. This approach has been adopted in this study where the 'entropy method' has been applied to assign weights to criteria. According to Hwang and Yoon (1981), this method is particularly useful to investigate contrasts between sets of data. For example, if a certain criterion has similar values for different alternatives, it can be considered not relevant for their evaluation.

Let p_{ij} be the probability of outcome of criterion (j) of alternative (i). It can be defined as follows:

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^n x_{ij}}, \quad (3a)$$

where all symbols are analogous to those in expressions (1) and (2).

The entropy E_j of the set of outcomes of criterion (j) can be determined as follows:

$$E_j = -k \sum_{i=1}^m p_{ij} \ln p_{ij}, \quad \forall j, \quad (3b)$$

where a constant $k = 1/\ln$ and m guarantees that $0 \leq E_j \leq 1$. If a DM has no reason to prefer one criterion over another, the best weight which he/she can use, instead of the equal weight, then (Hwang and Yoon, 1981)

$$w_j = \frac{1 - E_j}{\sum_{j=1}^n (1 - E_j)}, \quad \forall j, \quad (3c)$$

where $0 \leq w_i \leq 1$. Of course, incorporating the subjective weights of experts who may participate in the evaluation process can modify these weights (Hwang and Yoon, 1981).

5 APPLICATION OF THE PROPOSED METHODOLOGY

The application of the proposed methodology consists of: computing the indicators of network performance; assessment of the outcomes of the performance evaluation procedure against inputs; description of outcomes; and identification of a 'preferable' or 'promising' configuration of innovative bundling networks under given circumstances.

5.1 Description of the Inputs

The values of the 16 indicators of network performance taken from Table I have been computed for 15 rail-based network cases described in Section 2. This has been carried out for each route and sub-network identified with respect to particular cases of bundling networks. This approach has uncovered the existence of a high diversity of particular indicators across the routes and/or sub-networks of the same network and different networks. In order to simplify the use of diversity of information, the average (i.e., 'the typical') values of these indicators have been computed. Consequently, with the exception of three indicators (the 'size' of network (1), 'transport work' (13), and 'intensity of network services' (15), which have related to the network as a whole), all other indicators relate to the average ('representative' or 'typical') route of a bundling network. This guarantees a consistency of approach, which, at the same time, possesses advantages and disadvantages. The main advantage seems to be a high level of simplification and ease of use in the evaluation procedure. The main disadvantage seems to be a real

TABLE II Rail-based network values of selected indicators of network performance according to the SAW method

| Bundling network | Performance indicators ^a | | | | | | | | | | | | | | | |
|------------------|-------------------------------------|----------|----|----|------|------|------|------|------|------|-------|-------|-----------|------|------|---|
| | S | ARL | CT | F | SD | ATS | ATT | TT | ADD | ADS | ADT | CTT | TW | TP | INS | C |
| Point-to-point | 5/4 | 2009 | 26 | 1 | 84.0 | 26.6 | 75.5 | 48.0 | 2009 | 15.9 | 126.1 | 0.381 | 104 437 | 728 | 25.9 | — |
| Jamsankoski | 8/5 | 1121 | 42 | 7 | 12.0 | 38.0 | 29.5 | 12.0 | 1121 | 20.9 | 41.5 | 0.289 | 1 647 870 | 1597 | 294 | — |
| RailRoads | 2/2 | 607 | 45 | 4 | 22.6 | 58.0 | 10.5 | 3.7 | 607 | 42.7 | 14.2 | 0.261 | 399 526 | 2594 | 355 | — |
| RoadRailer | | | | | | | | | | | | | | | | |
| Trunk line-CD | | | | | | | | | | | | | | | | |
| Hub-and-spokes | 16/15 | 300–1670 | 40 | 7 | 12.0 | 40.3 | 24.1 | 1.0 | 766 | 31.8 | 25.1 | 0.382 | 3 564 760 | 1733 | 232 | — |
| Wembley EFOC | 37/37 | 60–2400 | 44 | 28 | 3.0 | 35.5 | 22.7 | 4.3 | 1619 | 31.4 | 51.7 | 0.083 | 9 576 292 | 1564 | 1186 | — |
| Hub of Metz | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 'Drehscheiben' | 8/7 | 100–750 | 65 | 4 | 21.0 | 32.3 | 5.4 | 28.8 | 370 | 9.2 | 40.3 | 0.715 | 4 667 612 | 2522 | 603 | — |
| The NEN | 11/10 | 100–750 | 40 | 7 | 12.0 | 20.6 | 5.8 | 6.0 | 350 | 15.2 | 23.0 | 0.261 | 9 100 000 | 1200 | 4550 | — |
| Bahntrans | 13/12 | 320–1250 | 43 | 9 | 9.3 | 45.2 | 19.7 | 24.0 | 862 | 19.7 | 43.7 | 0.549 | 5 414 264 | 1932 | 638 | — |
| Gateway | | | | | | | | | | | | | | | | |
| terminal 'Hupac' | | | | | | | | | | | | | | | | |
| Line or ring | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| Piggy-back | 10/1 | 167 | 82 | 35 | 2.4 | 23.7 | 7.0 | 1.6 | 167 | 19.4 | 8.6 | 0.186 | 623 200 | 1946 | 5438 | — |
| 'Ring-Zug' | 6/7 | 259 | 34 | 24 | 3.5 | 95.7 | 2.7 | 3.5 | 259 | 41.8 | 6.2 | 0.565 | 280 376 | 3378 | 537 | — |
| The 'Linienzug' | | | | | | | | | | | | | | | | |
| Mixed | | | | | | | | | | | | | | | | |
| Voltri | 9/8 | 140–500 | 27 | 7 | 18.9 | 60.0 | 4.2 | 33.0 | 251 | 6.8 | 37.2 | 0.877 | 373 329 | 1620 | 164 | — |
| Sogemar | 26/19 | 100–1500 | 27 | 3 | 28.0 | 45.7 | 20.3 | 28.0 | 647 | 14.3 | 45.3 | 0.552 | 1 052 973 | 1231 | 168 | — |
| FlexNode | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |

^aSee Section 3 and Table I for explanation of the abbreviations.

'danger' of losing important information on the characteristics of the networks due to a high level of aggregation of the performance indicators. The values of 16 indicators for 15 alternatives (the cases of the rail-based bundling networks) are given in Table II.

5.2 Assessment of Outcomes of Performance Evaluation Procedure

Using the SAW method, the evaluation procedure was carried out on 15 rail-based bundling networks. The ranked outcomes are presented in Table III.

As can be seen, among the three '*Point-to-Point*' bundling networks, the 'RoadRailer' network has emerged as the one with best estimated performance. The 'RailRoads' network has taken second place. The 'Jämsänkoski' network has the lowest estimated performance. The rail-based network of type '*Trunk Line with Collecting/Distribution Forks*' networks has not been identified in the sample analysed. As can be seen from Table III, six rail-based '*Hub-and-Spoke*' bundling networks have been evaluated. The 'preferable' or 'promising' network has emerged as

TABLE III The results of overall performance estimation with the SAW method

| <i>Rail-based networks</i> | <i>Performance (the SAW method)</i> | <i>Rank</i> |
|----------------------------|---|-------------|
| Point-to-point | | |
| 'Jämsänkoski' | 0.198 | 3 |
| 'RailRoads' | 0.686 | 2 |
| 'RoadRailer' | 0.745 | 1 |
| Trunk line-CD | — | — |
| Hub-and-spokes | | |
| 'Wembley EFOC' | 0.430 | 4 |
| 'Hub of Metz' | 0.569 | 1 |
| 'Drehscheiben' | — | — |
| 'The NEN' | 0.314 | 5 |
| 'Bahntrans' | 0.550 | 2 |
| 'Gateway' terminal 'Hupac' | 0.472 | 3 |
| Line or ring | | |
| Piggy-back | — | — |
| 'Ring-Zug' | 0.695 | 1 |
| The 'Linienzug' | 0.529 | 2 |
| Mixed | | |
| 'Voltri' | 0.585 | 2 |
| 'Sogemar' | 0.744 | 1 |
| FlexNode | — | — |

the 'Hub of Metz and the Quality-Net' (see Table III). Three '*Line*' or '*Ring*' bundling networks have been evaluated in this example. The outcomes shown in Table III indicate that the 'Ring-Zug Rhein-Rhur' has been identified as a 'preferable' network followed by the 'Linienzug concept'. Evaluation of the rail-based '*Mixed*' indicates that the 'preferable' or 'promising' concept is the 'Sogemar' network.

Thus, according to our SAW analysis, the rail-based bundling networks with the performances and layouts like the 'RoadRailer' (type '*Point-to-Point*'), 'Hub of Metz' (type '*Hub-and-Spoke*'), 'Ring-Zug Rhein-Rhur' (type '*Line*'), and 'Sogemar' (type '*Mixed*') would be considered as 'preferable' or 'promising'.

5.3 Identification of 'Preferable' Bundling Network(s)

The evaluation of the rail-based innovative bundling networks has provided a relatively solid base for building the blocks for a preferable network layout(s) (EC, 1998a). However, admittedly due to incompleteness of the relevant information (particularly on the monetary characteristics of the networks), it is only possible to draw preliminary conclusions.

Since the '*RoadRailer*' has emerged as a 'promising' concept in the class of '*point-to-point*' bundling networks, the network(s) like this could be considered as 'preferable' rail-based bundling configuration(s), whose characteristics may be synthesised as follows:

- The network consists of begin- and end-terminals where the purely sequential exchange of loading units between road and rail (and vice versa) takes place.
- The network serves relatively large and predictable freight flows in both directions, on distances varying approximately between 400 and 600 km.
- The large volumes of predictable and regular freight flows justify the operations of shuttle (or direct) trains with regular frequency. Frequency should be matched with demand (typically, one service per day or one service per two days seems to be quite acceptable). Flexibility in adaptation of train capacity to demand through changing frequencies and capacity of transit units (the trains) may make this concept 'beneficial' for operators and attractive for users (shippers) at the same time.

- The relationships between transport speed, delivery distance and total terminal time provide the level of quality of service A (delivery of shipments in 24 h) and/or B (delivery of shipment in 48 h).
- Operating trains of relatively large capacity by relatively high transport speed produces the concept's high technical productivity, intensity of the network services and transport work. These characteristics make this concept competitive to road-haulage in equivalent freight transport markets (characterised by similar volumes of freight and delivery distances) with respect to total delivery time, utilisation of available infrastructure and reduction of negative impacts on the environment.

The 'Hub of Metz and Quality Net' has been shown to be a 'promising' concept in the class of rail-based '*hub-and-spoke*' bundling networks. This implies that a network like this could be considered as a 'preferable' bundling network under given conditions. The general characteristics of such a network can be summarised as follows:

- The network is preferred to be as large as possible with respect to the number of terminals (the nodes) and routes (links). The hub terminal should be located at the intersection of important rail-lines ('axis'), i.e., at the 'central' location with respect to the location of the other terminals (spokes). It provides sequential exchange of rail wagons and/or wagon groups (i.e., loading units) between direct trains. The exchange time and thus the total terminal dwell time of loading and transit units can be shortened by a proper balance of inbound and outbound timetables.
- The terminals (spokes) should be located over a large area (like half of Europe) to provide high spatial accessibility of the network services and delivery of the loading units over a wide spectrum of distances (routes) (from several tenths (let us say 60) to a few thousand kilometres (2500)). Spatial location of terminals and high diversity of route lengths allows the establishment of different sub-networks (and thus segmentation of services), which begin and end at a common hub.
- The regular services by direct trains should be provided on each route to and from the hub. The frequencies should be sufficient, at least one per day, but they should be adjusted to demand, capacity and utilisation of trains too.

- Regarding frequency (i.e., schedule delay), delivery distance, average transport speed (20–40 km/h) and average terminal dwell time (about four hours), different types of quality of service can be offered. These are the quality A/B (delivery time up to 24 h on distances up to 800 km), A/C (delivery time up to 48 h on distances from 800 to 1600 km), and A/D (delivery time up to 72 h on distances over 1600 km).
- With respect to transport and delivery distances and distribution of route lengths in the network (long routes have prevailed), terminal dwell time may have a small influence on total delivery time. Therefore, the introduction of NG terminals in such a network to speed-up the exchange of loading units seems to be of little relevance and influence on overall network time performance.
- The network of such configuration and frequency on particular routes is able to replace high volume of transport work, which otherwise would be carried out by road haulage. Thus, it offers significant reduction in the negative effects on the environment over a wide area which otherwise would come from road haulage.
- A relatively high rate of coverage of a wide area by the terminals between which services of sufficient quality are provided may make the network a real competitive alternative to road haulage from the standpoint of shippers.

In the class of ‘*line*’ or ‘*ring*’ bundling networks, the ‘Ring-Zug Rhein-Rhur’ network has emerged as a ‘preferable’ concept. Therefore, the networks of this category can be considered to be ‘promising’ ones. They should have the following general performances:

- The network should consist of a relatively large number of terminals (say about 10), which are located at relatively short distances (about 30–40 km) along the line or ring. The terminals can be begin-, end- and intermediate-terminals. Sequential rail/rail and rail/road exchange of loading units can take place at these terminals.
- The network should cover a relatively small area (the region), which is able to generate and attract big, regular, predictable and dense freight flows. This will justify the operation of frequent shuttle trains (a few trains per day), which will deliver loading units very close to destinations, up to 30–40 km (regional transport) and up to 200 km (inter-(national) transport).

- High frequency (i.e., very short schedule delay), short delivery distance, acceptable transport speed and terminal dwell time guarantee delivery of loading units in at most one day (i.e., quality of service of type A can be offered). Thus, only extremely short-distance markets (10–20 km) may remain for road-haulage. Additional reduction of terminal dwell time may be achieved by introducing NG terminals, where simultaneous (pure and batch) exchange of loading units can take place. Shortening of terminal dwell time could additionally increase the competitiveness of such a network on short distances in comparison to road-haulage.
- High frequency and capacity of trains running on short distances produce a large transport work, which would otherwise be realised by road. Thus, decreasing the negative impacts on the environment by operating such a network could be evident and significant. At the same time, the utilisation of rail and terminal infrastructure could be improved.

The 'Sogemar network' has appeared as a 'preferable' concept in the class of 'mixed' rail-based bundling networks. Therefore, networks like 'Sogemar' could be considered as 'promising' or 'preferable' networks whose main characteristics are summarised as follows:

- The network consists of a large number of terminals where sequential exchange of loading units between the same and/or different transport modes takes place. This makes the terminals' dwell time and their layouts more dependent on inbound and outbound timetables than on the characteristics and efficiency of the terminal operations themselves. Different sub-networks operating independently from each other and being able to cover a large area are established between terminals. Each sub-network may include different transport modes like sea and rail. The rail (inland) portion of a sub-network should cover a wide spectrum of distances, from about 100 to 1500 km.
- Regular and frequent services by shuttle trains maximally matched to expected demand should be provided on particular inland routes.
- With respect to diversity of destinations, spatial density and length of delivery distances (routes), delivery speed and terminal dwell time(s), service quality of type A (daily delivery) can be provided. This makes the particular inland sub-networks competitive to road haulage.

Since the inbound and outbound timetable may dominate terminal dwell time, the effects of introducing NG terminals to increase overall terminal and network efficiency should be carefully considered.

- Like the other large rail-based bundling networks, this type of network and sub-network produces a large volume of transport work, intensity of network services and technical productivity. This may enable high utilisation of available rail infrastructure and significantly reduce the negative impacts of the equivalent activities of road haulage on the environment.

6 CONCLUSIONS

This paper has presented an evaluation of rail-based innovative bundling networks operated in the European freight transport system. The objective has been to identify 'promising' or 'preferable' network configurations with respect to a given set of indicators representing the networks' spatial, technological and operational performances. The cases analysed have been classified into sub-sets of bundling networks possessing a similar spatial and operational configuration like 'point-to-point' networks, the networks of 'trunk line with collecting/distributing forks', the 'hub-and-spoke' networks, the 'line' (or 'ring') networks and the 'mixed' network. The networks from each sub-set have been considered as alternatives. The indicators of network performance have been applied as criteria to an evaluation of particular network alternatives. The SAW method has been applied and the outcomes from the evaluation procedure have indicated that it has been possible to make some general conclusions and recommendations concerning 'promising' or 'preferable' configurations and the performance of rail-based innovative bundling networks as follows:

- The number of intermodal terminals should be dependent on the size of area where the network has been set up; it should be as large as possible in order to provide high spatial accessibility of network services.
- Routes should cover a wide spectrum of distances, from extremely short to extremely long.
- Frequency should be sufficient to serve expected demand, regular, and available as needed. Thus, it will provide high time accessibility of

network services (on the shorter routes with high-density demand several departures per day should be offered; on the longer routes at least one departure per day seems to be able to guarantee sufficient competitiveness of the network).

- Deploying the shuttle/block/direct train and/or barge should provide convenient transport capacity and attractive service.
- Delivery time should be standardised on a route-by-route basis. The quality of services A (up to 24 h), B (up to 48 h), C (up to 72 h), etc. should be offered. In addition, dependability, reliability and safety should be implicitly considered.
- Introduction of NG-terminals seems to have higher effects in networks of shorter routes where high density of demand is served by higher frequency of higher capacity transit units running at higher transport speeds. Otherwise, the effects of NG-terminals on network performance will be lower.
- Transport work, technical productivity and intensity of network services should be as high as possible to replace equivalent volumes of road haulage in the same market(s) and thus reduce its negative impacts on the environment.

Generally, this research into innovative bundling networks may be disseminated in a number of directions. First, other non-rail-based cases of bundling networks should be included in the evaluation. This has been partly carried out in the TERMINET project. Second, involving experts and representatives of particular interest groups should refine the weighting criteria procedure. Third, the implication of NG-terminals on changes in network performance should be additionally studied. Last but not least, the evaluation of bundling networks independently of dominant transport mode and type of bundling, and with respect to equivalent operations of road-haulage, should be tried in order to look for general 'preferable' or 'promising' configurations.

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